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Canada Centre for Mineral and Energy Technology | Centre canadien de la technologie des minéraux et de l'énergie

A PROPOSED DUST TUNNEL FOR THE CALIBRATION OF INSTRUMENTS
1. INITIAL DESIGN

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ELLIOT LAKE LABORATORY

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A PROPOSED DUST TUNNEL FOR THE CALIBRATION OF INSTRUMENTS
1. INITIAL DESIGN

by

S. Hardcastle*

ABSTRACT

To assess, compare and calibrate dust measuring instruments, standard and repeatable dust conditions are necessary. To facilitate this a recirculating dust tunnel has been designed whose fan requirements have been determined and construction outlined.

The dust tunnel is designed to give a wide range of stable air velocity and dust concentration conditions; the tunnel also includes two sampling volumes for the simultaneous assessment of instruments under different velocity conditions, but a common dust cloud.

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PROJECT DE SOUFFLERIE A ATMOSPHERE POUSSIEREUSE POUR ETALONNAGE D'APPAREILS DE MESURE

1. CONCEPTION INITIALE

par

S. Hardcastle*

RESUME

L'évaluation, la comparaison et l'étalonnage des appareils de mesure de l'empoussièrement nécessitent l'obtention de conditions standard répétables. On a à cette fin conçu une soufflerie à atmosphère poussiéreuse qui sera munie de ventilateurs dont les caractéristiques ont été déterminées et l'aspect précisé.

La soufflerie permettre de créer divers écoulements à vitesse stable et à empoussièrements variés. Elle sera aussi dotée de deux volumes d'échantillonnage, pour l'évaluation simultanée d'appareils dans des écoulements de vitesses différentes mais d'empoussièrement identique.

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INTRODUCTION

The Elliot Lake Laboratory presently employs a 2.0 x 2.5 x 1.8 m chamber in which dust measuring instruments may be calibrated or compared. In the new laboratory, projected for 1985, it is intended to replace this chamber by a tunnel.

Through a tunnel, a constant air and dust flow mixture may be produced. Such a system will provide an environment in which to calibrate instruments which is more comparable with the mining environs than that available to date.

This report documents the basic design criteria for the dust tunnel as based on flow considerations. It determines the duties and special requirements of the fan to be purchased and gives all the data necessary for constructing the system.

BASIC DESIGN REQUIREMENTS OF THE DUST TUNNEL

The dust tunnel is to be enclosed in a chamber which will be at negative pressure and HEPA filtered to avoid workroom and atmospheric contamination. The proposed dimensions of the chamber are: 9 m long, ≈2.80 m high and 2 m deep.

The tunnel will be primarily a closed-circuit duct system (in the vertical plane) through which dust laden air will be continuously circulated by a fan. Dust and/or air may be introduced into the tunnel to adjust internal dust concentrations and replace dust and/or air removed by measuring instruments. This allows balanced conditions to be established.

For the calibration or comparison of dust measuring instruments, the tunnel should provide flexibility of testing conditions, namely:

i) the sampling volumes should be suitably large to accomodate various instruments at any one time and be assumed to produce uniform dust

concentrations;

ii) the tunnel should contain at least two sampling volumes for simultaneous assessment under different velocity conditions, but in a common dust cloud, and

iii) complementary to the above, flexibility of flow rates, associated air velocities and of dust concentrations both jointly or independently is required.

The velocity range sought of the sample volumes is ≈0.125 m/s to 10 m/s. For two sample volumes with a velocity ratio of 4 between them, the individual ranges would be 0.125 - 2.5 m/s and 0.5 - 10 m/s. The lowest velocity may have to be increased to avoid excessive dust deposition and also the velocities should be sufficiently high to produce turbulent flow at all times.

Outside of the sample volumes, the cross-sectional area (C.S.A) of the tunnel should be smaller, to reduce the total volume of the system, increase air velocities to offset dust deposition and allow for bend design optimization.

PROPOSED LAYOUT, DESIGN CRITERIA AND SECTIONAL DIMENSIONS

The proposed dust tunnel layout is shown in Fig. 1. For ease of construction a square cross-section is preferred. The duct consists of two main sections: a small C.S.A. 'return' from the fan exhaust sweeping out 270° before entering the sampling area, and the variable C.S.A. duct of the sampling volumes and transition pieces.

The fan should be centrifugal with radial or paddle blades, which provide a 90° bend and the best dust handling capacity.

Allowing for easy access to the sample volumes when inside the chamber, auxiliary equipment and a comfortable working height, the occupiable volume of

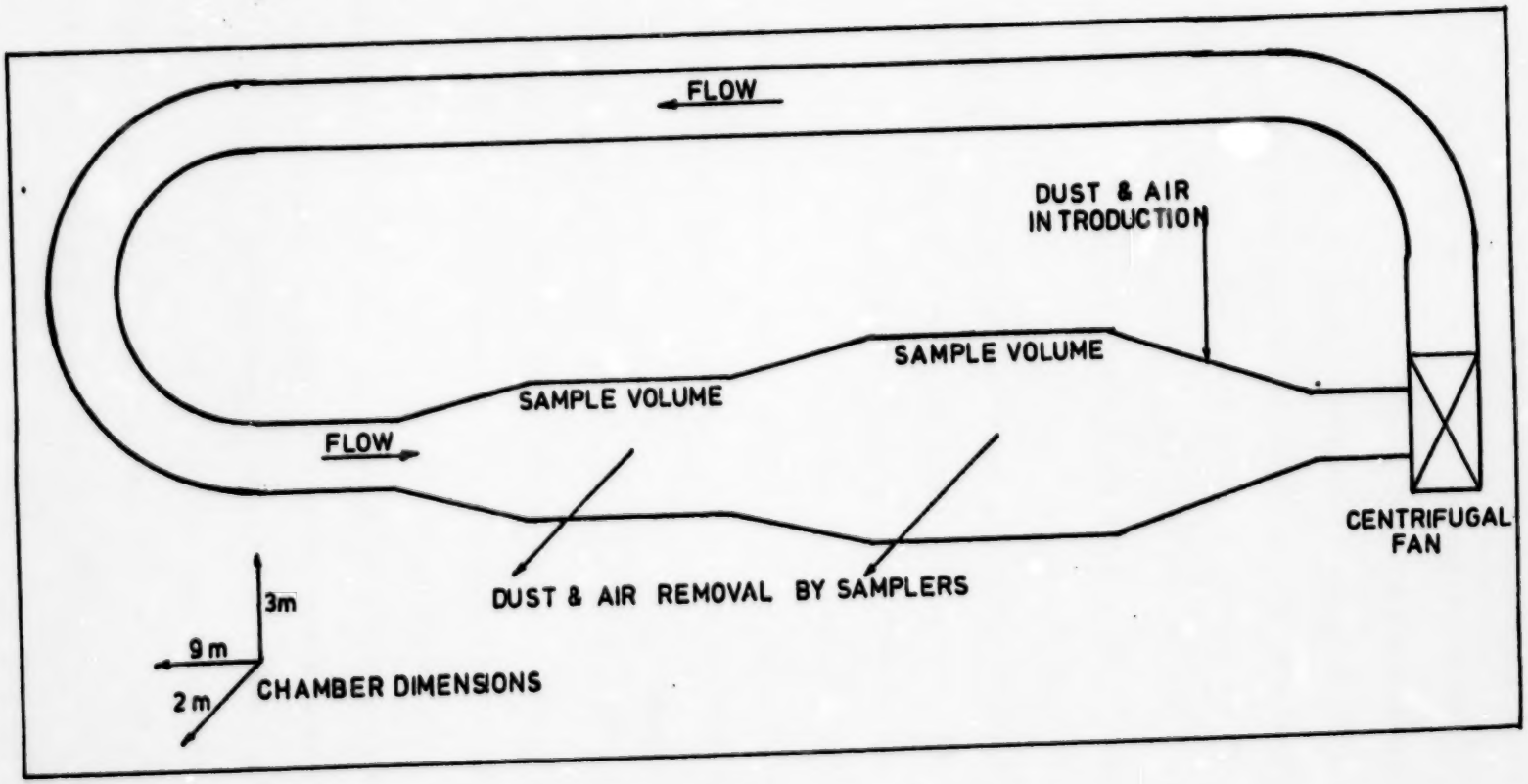

Fig. 1 - Proposed dust tunnel layout

the duct has been reduced to 9 x 2 x 1 m. In the duct, flow requirements and the following criteria (1,2,3,4), control the internal dimensions of the sample volumes and the return duct:

a) The return duct shall have a general C.S.A. of 0.0625 m^2, i.e., 0.25 x 0.25 m square (this increases the return velocity).

b) The 90° and 180° bends shall have a radius to diameter ratio, R/d = 3, i.e., 0.75/0.25, the centre bend radius being 0.75 m; this minimizes velocity pressure conversion (shock) losses. Note: this does not include duct wall thickness.

c) Each diffuser section to the sample volumes shall be gradual, 8.5° to the horizontal and have the area ratios of 3.24 and 3.57 (this maximizes velocity pressure conversion and avoids flow separation).

d) The sample volumes shall have C.S.A.'s 0.2025 m^2, i.e., 0.45 x 0.45 m, and 0.7225 m^2, i.e., 0.85 x 0.85 m. These have been optimized to reduce the return duct velocity and in association with optimum lengths in the overall duct system.

e) The contraction which is less critical than the diffusers shall have an angle of 10.5° to minimize pressure losses. This section shall return the duct back to the 0.25 x 0.25 m size square section.

Other considerations include:

1. The bends will include guide vanes, which aid flow straightening, reduce compression of the flow to the outside of a bend and reduce velocity pressure losses, but they do tend to increase frictional pressure losses. Three vanes have been selected at centre radii 0.68, 0.739 and 0.804 m.

2. The lengths of the horizontal straight sections shall be maximized to promote uniform stable flow conditions both in and out of the sampling volumes.

3. The top return section allows for the accomodation of a Standard bulk airflow measurement device which will be a Venturi; this requires a circular cross-section, (a diameter of 0.282 m maintains the same C.S.A.). Square to round transition pieces are also required.
4. The dimensions of the Standard Venturi and its positioning (5) have been optimized for the flow conditions. A Venturi is the least pressure destructive and flow disruptive device commonly used for airflow measurement.
5. To reduce dust deposition purely in the large sampling volume the minimum velocity has been raised to 0.162 m/s.
6. The quantity range in the system is 2.025 → 0.117 m^3/s, i.e., a ratio of 17.3:1. To obtain this, according to the Fan Laws, the fan must have the same speed range ratio; this is unobtainable with common direct fan motor electrical controls, hence a variable pulley system shall also be included. Despite this, it may still be necessary to reduce the quantity range down to 8:1 or less.
7. An out of line fan motor with pulley drive is preferred; this reduces the overall length contribution of the fan and drive in the dust chamber.

The final selected dimensions are given in Fig. 2. It is suggested that the duct be predominantly constructed of 2-3 mm steel apart from the Venturi and its up-and down-stream pipelines. The pipelines may be constructed from commercially available pipe.

Excluding duct thickness and connecting flanges the overall dimensions of the designed duct are, 8.75 x 2.066 x 0.85 m.

MEASUREMENT AND CONTROL

Control of dust and/or airflow in the duct are important. Primary airflow control is given by a variable speed fan, the duties of which this

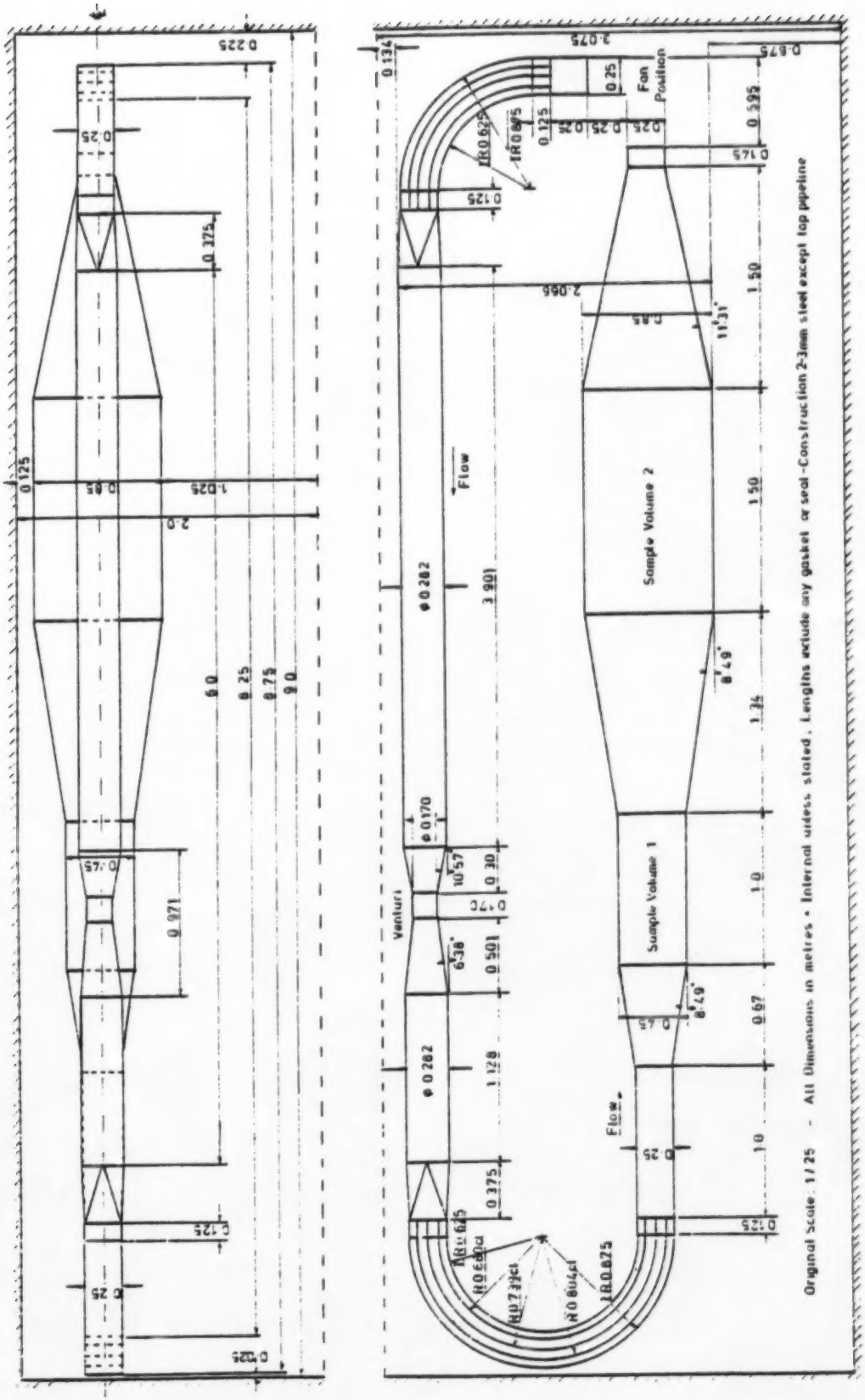
Venturi
Flow
Sample Volume 2
Sample Volume 1
Fan Position
Original Scale: 1/25 - All Dimensions in metres • Internal unless stated. Lengths exclude any gasket or seal -Construction 2-3mm steel except top pipeline

Fig. 2 - Final selected dimensions of the dust tunnel.

report will initially determine.

Dust is to be introduced into the system at a high concentration in the contracting section. This is the furthest possible flow distance away from the sampling volumes and hence gives the greatest time for turbulent dispersion to a uniform dust concentration. The dust source is also prior to the fan, therefore all dust in the recirculating airstream at the sampling volumes has been subject to the effects of the fan. This should help stabilize concentrations in the sample volumes.

The contraction section will also house a resistance grill to further promote mixing of newly introduced dust and provide secondary airflow control.

Dust sampling/measuring instruments commonly remove air and/or dust from the system, these will have to be replaced where the dust is introduced to maintain a balanced system.

Airflow measurement can be easily achieved by a pressure device, e.g., the Venturi in the return section. In the sampling volumes the flow/velocity distribution can be obtained by Pitot tubes.

Of the above inclusions, the resistance grill and the Venturi significantly add to the resistance of the dust tunnel and must be included in the determination of fan duties.

FAN DUTIES AND FAN SPECIFICATIONS

Duties and specifications of the fan in the dust tunnel already determined are:

a) A centrifugal unit, inlet horizontal, outlet vertical.

b) It must be dust handling, that is radial or paddle bladed and safe for explosive dusts.

c) The drive must be out of line, and preferably with a pulley system.

d) The quantity delivery range desired is 0.117 to 2.025 m^3/s; this requires a variable speed drive arrangement.

Other considerations are: air relative humidity, this will generally be normal, but may be desired up to 90%. Also the fan casing should be sealed to avoid leakage into or out of the unit at the drive shaft.

The remaining requirement to specify the fan is its pressure creation both Total and Static for the maximum and minimum flow rates. These have been calculated in Appendix A using the following assumptions:

i) A standard air density of 1.2 kg/m^3.

ii) A standard air barometric pressure 100 kPa.

iii) A standard air viscosity 1.8×10^{-5} Ns/m^2.

iv) An average surface roughness height of 0.15 mm, this is equivalent to that of galvanized steel.

v) All frictional pressure losses per section have been determined using the Darcy-Weisbach flow equation in the form:

$$\Delta P = \lambda \rho \frac{L}{d} \frac{V^2}{2}$$

where, ΔP = pressure drop, (Pa, N/m^2)

λ = friction factor, (dimensionless)

ρ = fluid density, (kg/m^3)

L = length, (m)

d = diameter of pipe (hydraulic), (m)

V = overall fluid velocity, (m/s)

vi) Velocity pressure conversion (shock) losses and the effects of fitting/transitions are also included (1,2,3,5).

vii) Changes in static pressure resulting from changes in elevation have also been included.

viii) An air specific heat ratio of 1.4 has been assumed.

ix) 10% has been added to the static pressure requirements to account for the resistance of auxiliary units to be included in the system. These could comprise; dust samplers, surface charge removers, humidity controllers and associated peripherals.

x) Dust has been assumed not to significantly affect any of the air's properties at the concentrations considered, ≤ 20 mg/m^3.

Using the above assumptions the following static, P_{fs}, and Total, P_{fT}, pressure requirements have been determined. These pressures are for the maximum and minimum flow conditions, and are between the 0.0625 m^2 C.S.A. fan inlet and outlet sections of the designed duct. Note pressure changes because of the difference in elevation of the inlet and outlet points have been included.

Under the two flow conditions the pressure profiles for the system are shown in Fig. 3 and 4. These are a graphical form of the pressure losses through the system as determined in Appendix A. Including a 10% safety margin on the static pressures the fan duties are as follows:

@ $Q = 2.025$ m^3/s : $P_{fs} = 1050$ Pa , $P_{fT} = 2580$ Pa
($\approx$4300 cfm) ($\approx$7.8" wg) ($\approx$10.4" wg)

@ $Q = 0.117$ m^3/s : $P_{fs} = 14.2$ Pa , $P_{fT} = 16.3$ Pa
($\approx$250 cfm) ($\approx$0.06" wg) ($\approx$0.07" wg)

The resistance of the system under these two conditions are 475 Ns^2/m^8 and 1037 Ns^2/m^8 respectively. The difference is due to:

i) The resistance screen in the contraction being closed under the low flow condition to provide resistance against the fan, whereas it is open for the high flow.

ii) The resistance naturally increases at lower flows as the surface roughness of the duct becomes more significant.

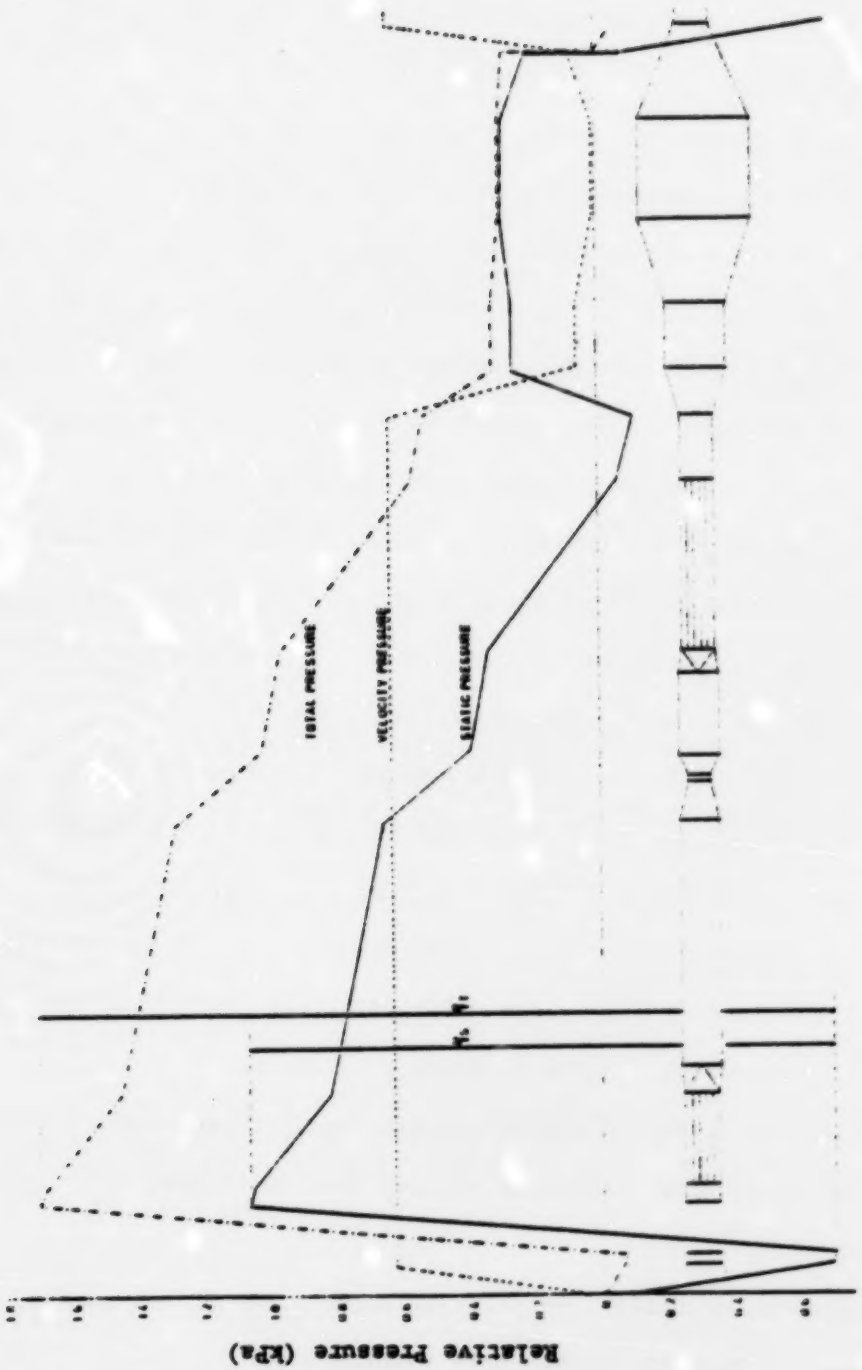

Fig. 3 - Pressure profile around tunnel at airflow rate 2.025 m³/s.

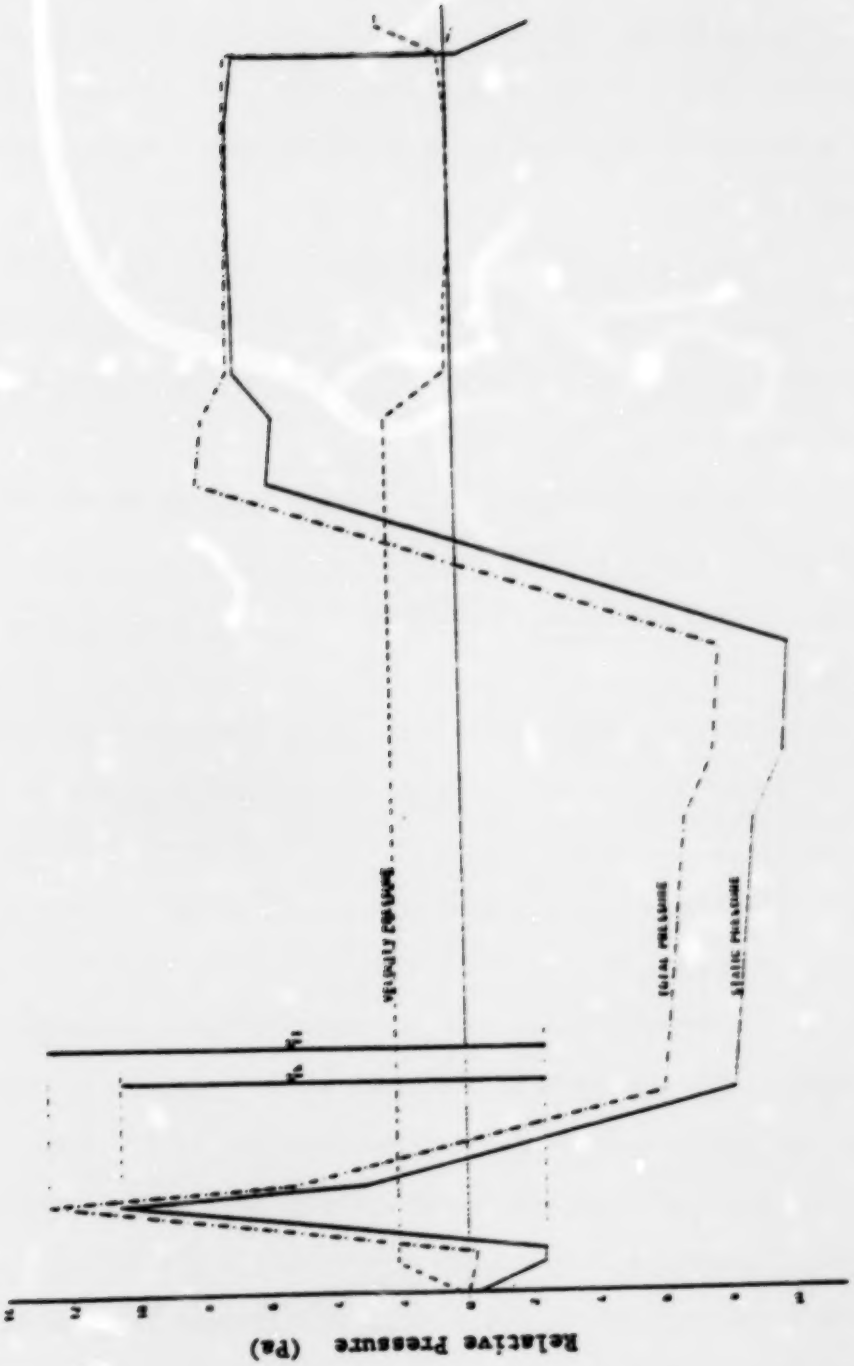

Fig. 4 - Pressure profile around tunnel at 0.117 m³/s.

CONSTRUCTION AND MANUFACTURE OF THE TUNNEL AND PERIPHERALS

For the general construction of the square cross-section ducting, steel sheeting is suggested, this may be up to 2-3 mm thick depending on the rigidity provided. The duct should be composed of sections each with flanges, such that they may be bolted together to allow for easy assembly and dismantlement of the system.

Gaskets or seals should be placed between flanges to provide airtight seals. The thickness of these is included in the overall dimensions quoted in Fig. 2 and must be deducted from section lengths as the overall length of the system is critical.

To increase the flexibility of the system a second set-up of sample volumes should be catered for. This requires:

i) that the two diffusers can be combined, hence the flanges should be compatible;

ii) that the small C.S.A. duct may be extended to form the first sample volume, thus an extra section (not shown) of 1.0 x 0.25 x 0.25 m is needed.

To facilitate the easy changing of sample volumes, it is suggested that the initial horizontal section to the sampling volumes include an angled joint $\approx 30°$ from the vertical.

For the two bends, special construction to include the guide vanes will be necessary. The thickness of the vanes although taken in calculations at a maximum 3 mm may be much thinner to ease formation of the bends.

The circular, upstream and downstream pipelines to the Venturi may be constructed of commercially available pipe. Ideally the diameter of this pipe should be as quoted 0.282 m, but a slightly different size may be used if agreed in consultation with the author. A limiting range of diameters would be 0.276 to 0.287 m.

The size of the circular pipeline will also affect the dimensions of the Venturi and these will also have to be finalized with the author. The Venturi will need machining in two or more parts - the tolerances on its manufacture are given in Appendix B.

A resistance screen is to be included in the convergent section of the duct after the second sample volume. This screen is composed of two main parts, which are flat metal plates, both have horizontal slots. One plate is fixed and the second moveable, allowing adjustment of the size of the open area of the screen. The enclosure of the screen should be airtight. The screen should also have some external indication of the degree of opening. The thickness of the screen is included in the quoted length of the convergent section. A suggested design for the screen is given in Appendix B.

Also to be included in the convergent sections are:

i) an inlet for the introduction of dust and air to replace that removed from the system; and

ii) an outlet for bleeding/cleaning the system.

The general requirements of both of these is given in Appendix B. The outlet is to be in the bottom of the convergent section prior to the resistance screen, and the inlet will be in the top of this section after the screen. A special requirement of the inlet is that it be from a secondary enclosed volume.

The construction and design of the sample volumes also requires special consideration. These sections are to include dust measuring apparatus that will need various external connections and airflow measuring equipment. The requirements of these, given in Appendix B, are summarized as follows:

i) Transparent sections are required in the top and outward side of each sample volume, the suggested material is glass or PVC.

ii) Quick release removeable airtight doors are needed on the outside of each sample section for installation and removal of instruments. These

may be incorporated with (i);

iii) In each section on the outward side a pitot-tube installation is to be included. These have special housing requirements.

iv) In the top and bottom of each sample volume, sections must be provided that can be easily tapped to introduce cables and/or tubing as required by the various air measuring instruments. The suggested material is wood and these may be incorporated with (i).

All inclusions in the sample volumes must be airtight and where possible flush with the internal surface.

Access doors should also be provided in the 0.25 x 0.25 m sections, off the fan and in the horizontal section to the sample volumes.

Wherever possible internal roughness from joints and welding should be minimized. This is especially important in the top pipeline and Venturi.

STRUCTURAL SUPPORT OF THE DUST TUNNEL

Support of the weight of the tunnel can be from either roof members or from the floor. The back and side walls may be used for stability. Finalization of available or required support will have to be obtained in consultation with structural engineers and the architects of the new laboratory.

CONCLUSIONS

A recirculating air and dust duct system has been designed based predominantly on flow requirements. This system is to be installed in the new Mines Research Laboratory at Elliot Lake.

The duct has been designed so that it will produce a wide range of steady-state dust concentrations and flow conditions under which to calibrate and assess dust monitors.

Resulting from this basic design the fan duties have been obtained for proposed maximum and minimum flow conditions.

Included in the design are peripheral requirements for measuring and controlling dust and/or airflow in the system.

In the overall design of the duct, space is limited so the dimensions are critical and must be adhered to. However, the suggested methods of construction, materials and design of peripherals or inclusions are flexible and alternatives may be used after consultation.

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APPENDIX A - PRESSURE LOSSES IN THE DESIGNED DUST TUNNEL

Pressure losses in the duct system comprise:

i) frictional pressure losses;

ii) velocity pressure conversion and shock losses;

iii) static head loss at changes of elevation.

Frictional losses are generally based on the Darcy-Weisbach relationship:

$$\Delta P = \rho \lambda \frac{L}{d} \frac{V^2}{2}$$

where, ρ = air density and assumed to be 1.2 kg/m

λ = friction factor, this is dependent on surface roughness and Reynolds number and can be obtained for use in the above equation from a Moody diagram (1).

In all determinations of λ a surface roughening height of $\varepsilon = 0.15$ mm has been assumed. Surface roughness then being given by ε/d.

Reynolds Number is defined as:

$$Re = \frac{\rho d V}{\mu}$$

where, μ = air viscosity and assumed to be 1.8×10^{-5} Ns/m^2

For non-circular ducts the diameter d is replaced by the hydraulic mean diameter d_h, this is defined by:

$$d_h = \frac{4A}{O}$$

where, A = cross-sectional area of the duct (m^2)

O = perimeter of duct (m).

For a square duct d_h equals the side dimension of the duct. Frictional pressure drops in the transitions, diffusers and contractions are calculated from the mean pressure loss per metre of the adjoining horizontal sections.

Velocity/shock losses are calculated using tables of empirically obtained loss factors, related to velocity pressure; this is calculated as:

$$V_P = \tfrac{1}{2}\rho V^2$$

Static head losses are calculated as:

$$P_s = \rho g h$$

where, h = change of elevation (m)

For the bends which include guide vanes the flow parameters and pressure losses have been calculated for a maximum vane thickness of 3 mm. This should be reduced in the actual duct, but the actual thickness will be determined by rigidity of the vanes in the bend and construction.

In Table A1, Reynolds Number varies in the guide vaned section as the vanes do not equally divide the section. The position of these vanes is in accordance with ASHRAE (1).

None of the available references gave frictional losses for long bends containing guide vanes. The effective resistance of such a bend has been calculated by summating the resistance of each parallel flow zone. For the designed bends the equivalent length was determined as $\approx 18\ d_h/90°$.

Tables A2 and A3, respectively, present the pressure losses of the duct system including resistance grill at high and low flow rates.

Table A1 - General flow conditions and cross-section dimensions

Duct Cross-section and Interval Dimensions	Cross-Sectional Area (m^2)	High Flow Rate Volume Flow (m^3/s)	High Flow Rate Flow Velocity (m/s)	High Flow Rate Reynolds Number	Low Flow Rate Volume Flow (m^3/s)	Low Flow Rate Flow Velocity (m/s)	Low Flow Rate Reynolds Number
Square Return 0.25 x 0.25 m	0.0625	2.025	32.40	540 000	0.117	1.872	31 200
Square Return with 3 x 3 mm Guide Vanes 0.25 x 0.25 m	0.0602	2.025	33.61	195 834 ↓ 242 216	0.117	1.942	11 323 ↓ 14 002
Circular Return 0.282 m ϕ	0.0625	2.025	32.40	609 120	0.117	1.872	35 194
Small Square Sample volume 0.45 x 0.45 m	0.2025	2.025	10.00	300 000	0.117	0.578	17 340
Large Square Sample volume 0.85 x 0.85 m	0.7225	2.025	2.80	158 823	0.117	0.162	9 180

Table A2 - Pressure losses in the duct system calculated for 2.025 m^3/s airflow rate.

Section	Length (m)	Hydraulic Diameter (m)	Velocity Pressure (Pa)	Friction Factor, λ	Pressure Losses: Friction (Pa)	Velocity (Pa)	Head (Pa)	Total (Pa)	Section Inlet Pressure: Total (Pa)	Static (Pa)	Comments
Half contraction	0.440				30.51	582.37	0	612.88	0	-75.41	Mean of 2 ducts, Vp loss 5%.
Fan inlet	0.145	0.25	629.86	0.0182	6.65	0	0	6.65	-58.43	-688.29	
Fan							In Outlet	(-1772.68)	-65.08	-694.94	
Fan outlet	0.250	0.25	629.86	0.0182	11.46	0	7.36	18.82	1707.60	1077.74	+ .375 m elevation through fan.
90° bend & vanes	1.428	0.25	(677.80)	0.0182	217.80	6.78	10.30	234.88	1688.78	1058.92	Effective length 19 d_h = 4.75 m Vp loss 1%.
Transition	0.375	0.25	629.86		15.92	0	0	15.92	1453.90	824.04	Mean of 2 ducts.
Upstream Venturi	3.760	0.282	629.86	0.0175	146.97	0	0	146.97	1437.98	808.12	Length - .141 m to Venturi tapping
Venturi	1.112				263.71	In friction	0	263.71	1291.01	661.15	Length + .141 m to Venturi tapping Loss 8.25% of measured.
Downstream Venturi	1.128	0.282	629.86	0.0175	44.09	0	0	44.09	1027.30	397.44	
Transition	0.375	0.25	629.86		15.92	0	0	15.92	983.21	353.35	Mean of 2 ducts.
180° bend & vanes	2.606	0.25	(677.80)	0.0182	401.22	9.49	-17.66	393.05	967.29	337.43	Effective length 35 d_h = 8.75 m Vp loss 1.4%.
Inlet pipe	1.000	0.25	629.86	0.0182	45.85	0	0	45.85	574.24	-55.62	
1st diffuser	0.670				16.12	-375.99	0	-359.87	528.39	-101.47	Mean of 2 ducts, Vp loss 31%.
1st sample volume	1.000	0.45	60.00	0.0170	2.27	0	0	2.27	318.40	258.40	
2nd diffuser	1.340				1.58	-34.89	0	-33.31	316.13	256.13	Mean of 2 ducts, Vp loss 34%.
2nd sample volume	1.500	0.85	4.71	0.0175	0.14	0	0	0.14	294.15	289.44	
Half contraction	1.060				3.88	74.27	0	78.15	294.01	289.30	Mean of 2 ducts, Vp loss 5%.
Resistance Screen			75.41		286.56	In friction	0	286.56	286.56	211.15	Friction & Vp loss = 3.8 Vp.
								0	-75.41		
Totals	18.189				1510.65	262.03	0	1772.68			

Table A3 - Pressure losses in the duct system calculated for 0.117 m^3/s airflow rate.

Section	Length (m)	Hydraulic Diameter (m)	Velocity Pressure (Pa)	Friction Factor, λ	Pressure Losses: Friction (Pa)	Pressure Losses: Velocity (Pa)	Pressure Losses: Head (Pa)	Pressure Losses: Total (Pa)	Section Inlet Pressure: Total (Pa)	Section Inlet Pressure: Static (Pa)	Comments
Half contraction	0.440				0.139	1.944	0	2.083	0	-0.252	Mean of 2 ducts, Vp loss 5%.
Fan inlet	0.145	0.25	2.103	0.0248	0.030	0	0	0.030	-0.232	-2.335	
Fan							In Outlet	(-12.912)	-0.262	-2.365	
Fan outlet	0.250	0.25	2.103	0.0248	0.052	0	7.36	7.412	12.650	10.547	+ .375 m elevation through fan.
90° bend & vanes	1.428	0.25	(2.263)	0.0248	0.991	0.023	10.30	11.314	5.238	3.135	Effective length 4.75 m, Vp loss 1%.
Transition	0.375	0.25	2.103		0.072	0	0	0.072	-6.076	-8.179	Mean of 2 ducts.
Upstream Venturi	3.760	0.282	2.103	0.0234	0.656	0	0	0.656	-6.148	-8.251	- .141 m to Venturi tapping.
Venturi	1.112				0.884	In Friction	0	0.884	-6.804	-8.907	+ .141 m to Venturi tapping, Loss 8.25% of measured.
Downstream Venturi	1.128	0.282	2.103	0.0234	0.197	0	0	0.197	-7.688	-9.791	
Transition	0.375	0.25	2.103		0.072	0	0	0.072	-7.885	-9.988	Mean of 2 ducts.
180° bends & vanes	2.606	0.25	(2.263)	0.0248	1.825	0.032	-17.66	-15.803	-7.957	-10.060	Effective length 8.75 m Vp loss 1.4%.
Inlet pipe	1.000	0.25	2.103	0.0248	0.209	0	0	0.209	7.846	5.734	
1st diffuser	0.670				0.074	-1.256	0	-1.182	7.637	5.534	Mean of 2 ducts, Vp loss 31%.
1st sample volume	1.000	0.45	0.200	0.0274	0.012	0	0	0.012	6.916	6.716	
2nd diffuser	1.340				0.008	-0.116	0	-0.108	6.904	6.704	Mean of 2 ducts, Vp loss 34%.
2nd sample volume	1.500	0.85	0.016	0.0315	0.001	0	0	0.001	6.828	6.812	
Half contraction	1.060				0.018	0.248	0	0.266	6.827	6.811	Mean of 2 ducts, Vp loss 5%.
Resistance screen			0.252		6.797	In Friction	0	6.797	6.797	6.545	Friction & Vp loss = 27 Vp.
									0	-0.252	
Totals	18.189				12.307	0.875	0	12.912			

APPENDIX B - SPECIFIC DESIGN REQUIREMENTS

DIMENSIONS AND SPECIFICATIONS OF THE VENTURI

A Standard Venturi is shown in Fig. B1, its design and specifications are derived from British Standard 1042 (5).

The Venturi and pressure tappings shall comply with the following:

i) It consists of a cylindrical entrance section, followed by a conical section leading to a cylindrical throat and a divergent conical outlet section.

ii) The internal design diameter, D, of the carrier pipe is 0.282 m.

iii) The selected internal diameter, d, of the throat is 0.17 m.

iv) Circularity of throat: the throat shall by cylindrical with all diameters agreeing within ± 0.001 d.

v) Length of throat: this shall be 1.0 d.

vi) Cylindrical entrance section: this shall have a length of not less than 1.0 D. Note: in Fig. 2 of the duct system the entrance section has been included in the total length of the upstream pipeline.

vii) Conical entrance section: this shall have a taper of 10.5° ± 1°, 10.57° has been selected.

The corner between the conical and cylindrical entrance sections may be rounded, but the radius shall not be greater than 1.8 D.

The corner between the conical section and the throat may be rounded, but the radius shall not be greater than 5.5 d.

viii) Divergent outlet section: this shall have a taper of 2.5 to 7°, 6.38° has been selected.

ix) Smoothness of internal surfaces: it is recommended that the internal surface of the entrance, conical inlet and throat sections be smooth to within ± 0.0003 d peak-to-hollow height.

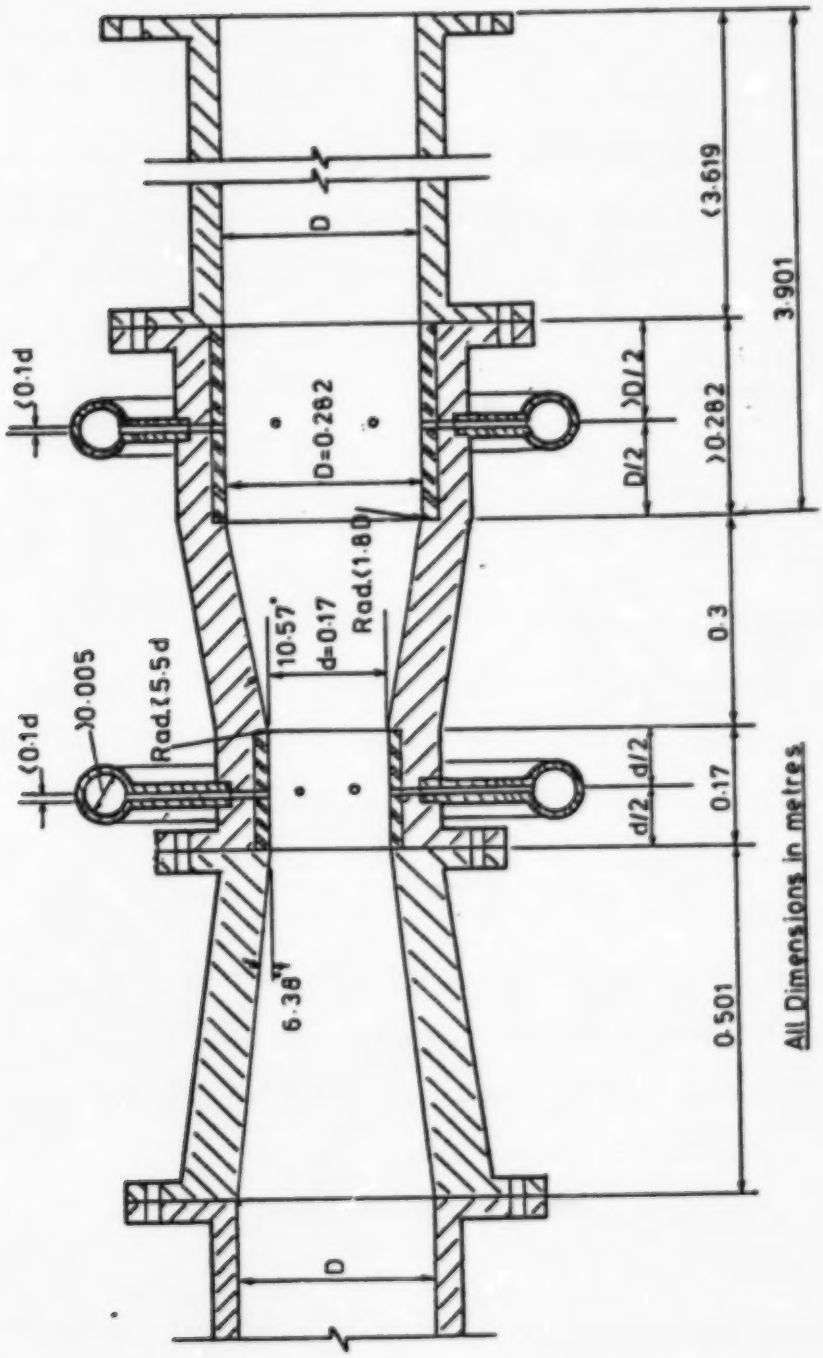

Fig. B1 - The Venturi tube.

It is, however, permissible that the internal surface of the unit be cast smooth provided the cylindrical entrance and throat sections consist of machined liners as shown.

x) Location of upstream pressure tappings: the upstream holes shall be located in the cylindrical entrance section at a distance 0.5 D from the conical section ± 0.05 D. The diameter of the pressure holes shall be $\leq$0.1 d measured parallel to the pipe axis.

xi) Location of downstream tappings: the downstream pressure holes shall be located in the throat at a distance 0.5 d downstream of the conical section ± 0.5 d. The diameter of the holes shall be $\leq$0.1 d.

xii) Minimum length of pressure holes: the diameter of a pressure hole shall remain constant for a distance not less than two diameters before expanding into a pressure pipe.

xiii) Finish of pressure holes: the pressure holes must break cleanly through the pipe wall with no projecting burrs, the edges may be rounded providing it does not exceed 0.1 of the diameter of the hole.

xiv) Circumferential location of tappings: six tappings shall be placed equidistant around the circumference starting at the horizontal.

xv) Piezometer Ring: all tappings shall be connected to a circumferential ring with one outlet. The internal diameter of the ring shall be >0.005 m.

DESIGN OF THE RESISTANCE SCREEN

A resistance screen to be included in the convergent section after the second sample volume is shown in Fig. B2. Its position in the duct is shown in Fig. B3.

The resistance screen shall be predominantly composed of two plates, each 0.003 to 0.005 m thick, of which one shall be fixed and the second moveable. The face dimensions of the two plates are:

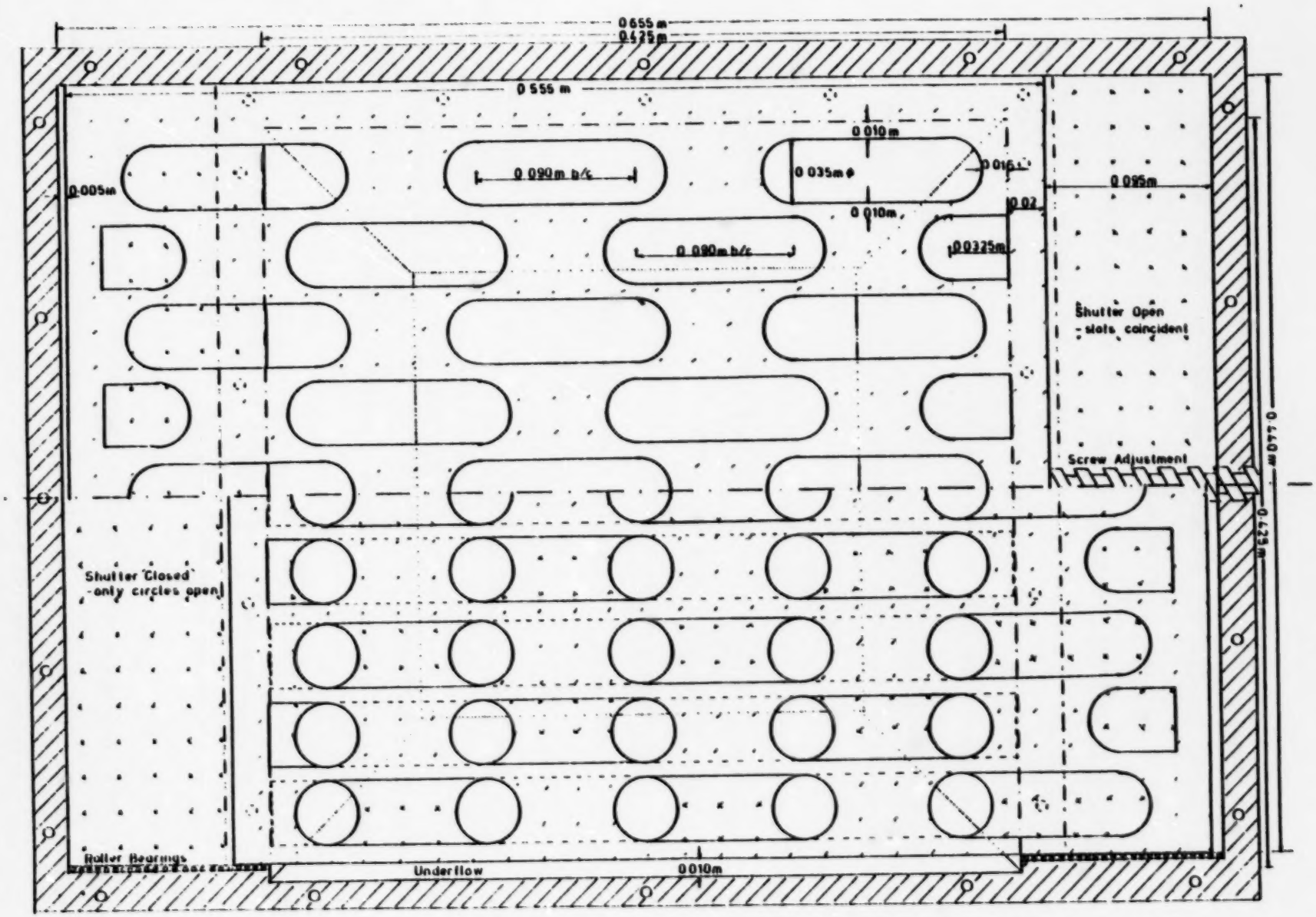

Fig. B2 - Resistance screen to be included in duct system.

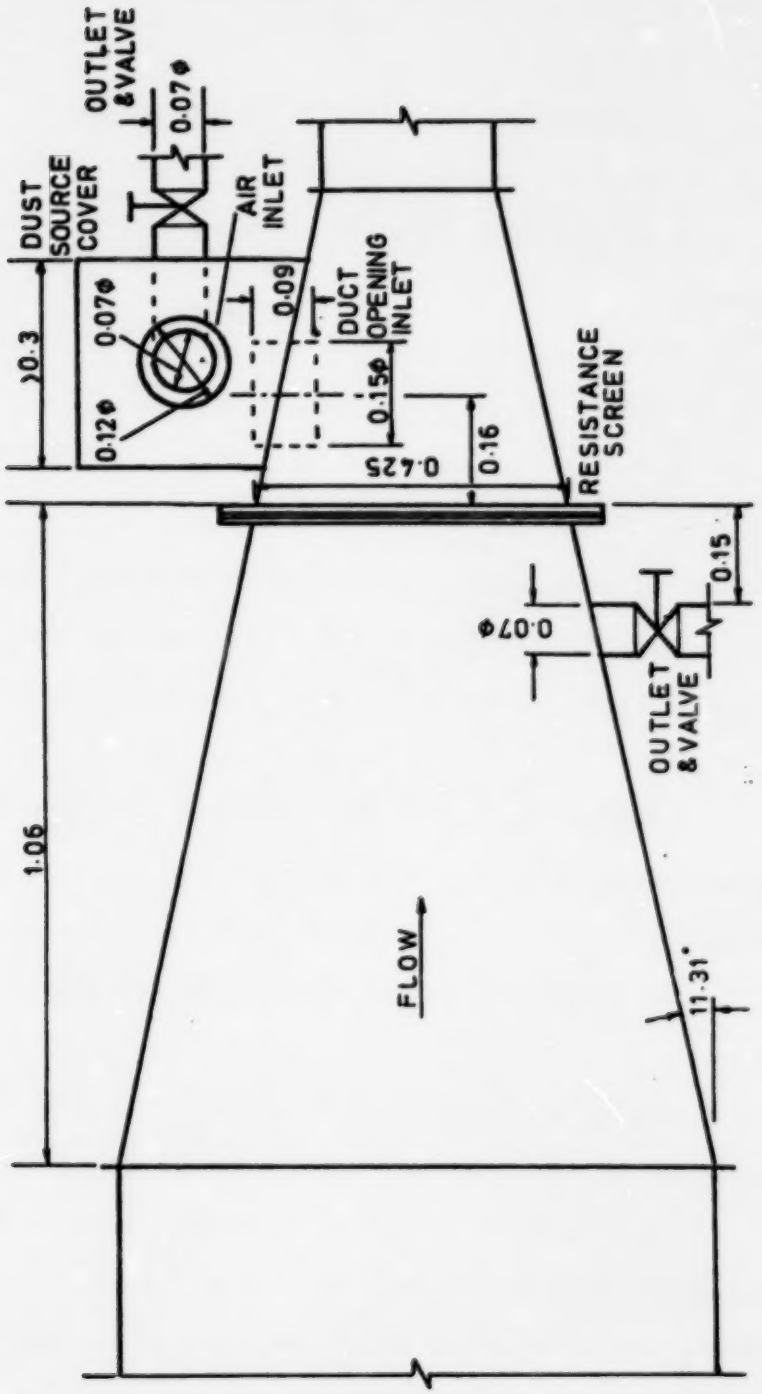

Fig. B3 - Convergent section arrangements.

i) Fixed plate - this is the rear plate to the direction of flow; not including the surround width, the dimensions are 0.655 x 0.440 m.

ii) Moveable plate - this is the front plate and has the absolute dimensions 0.555 x 0.44 m.

Both plates are horizontally slotted with holes 0.125 m long, these consist of two 0.035 mø half-circles with 0.09 m between centres.

In the vertical plane the slots are offset by 0.09 m with 0.01 m separation.

The area of the two plates slotted is:

a) In the fixed plate only the area coincident with the duct is slotted, that is 0.425 x 0.415 m, the remaining 0.01 m in the 0.425 x 0.425 m sectional area of the duct is left as an underflow.

b) In the moveable plate, the whole area is slotted excluding margins.

The slots in the plates should be made so that when the screen is open the slots are coincident, and when the screen is closed only 0.035 mø circles remain open. This is shown in Fig. B2.

To adjust the screen hole apertures a mechanical device needs to be attached to the moveable plate, a screw is shown; this device must have some external indication relating to the size of aperture in the screen.

The moveable plate may also require bearings to rest on to allow free movement.

A third plate will also be necessary to cover the front of the screen external to the duct area, excluding surround this plate will be 0.655 x 0.450 m with an open area ≈0.425 x 0.425 m coincident with the duct. The actual dimensions of this opening will have to be increased in relation to the total thickness of the three plates and the angle of the convergent section. This is to avoid increasing the length of the convergent section beyond 1.5 m which is critical.

Generally the whole unit should be airtight to avoid leakages. Also the holes should be smooth and free of burrs.

DUST AND/OR AIR INTAKE AND EXHAUST FOR THE DUCT SYSTEM

The duct system shown in Fig. 2 should be totally airtight apart from the following exclusions:

1. To rapidly reduce internal dust concentrations or flush the system an exhaust is required from the system. This may simply be a pipeline with a valve ultimately connected to the HEPA exhaust system of the chamber. For this the duct should have a 0.07 mø pipe with stop valve in the base of the convergent section before the resistance screen, as shown in Fig. B3.
2. The dust and air intake to the duct system needs special provisions. It is required that the system is virtually at atmospheric pressure where the dust is introduced. To allow this a second chamber open to atmosphere shall surround the point of dust introduction. To avoid workplace contamination this chamber should also be connected into the HEPA system. Fig. B3 shows the suggested arrangement.

A 0.15 mø x 0.09 m circular pipe is included vertically in the top of the contraction zone beyond the resistance screen; this provides shrouding of the dust source, both externally and internally of the duct. The dust source will be a pipe from a dust generator that may be positioned in this protected area.

Surrounding the circular pipe on the outside of the duct shall be an enclosed volume of >0.3 x 0.3 x 0.3 m as compatible with the convergent section. This enclosure may be made of steel.

The open side of this enclosure is open to atmosphere via a centrally positioned 0.12 mø hole. On the opposite side, adjacent to the back wall of the chamber an exhaust connection is needed. This shall be a ≈0.07 mø pipe

with a stop valve.

On both the exhaust pipelines to the HEPA filter, in 1) and 2), it will be desirable to have a rotameter to measure airflow when required.

DESIGN OF SAMPLE VOLUMES

There are three sample volume sections for the duct system:

a) 0.25 x 0.25 x 1.00 m

b) 0.45 x 0.45 x 1.00 m

c) 0.85 x 0.85 x 1.50 m

These have either a) and c) or b) and c) combinations in the duct system.

To allow for installation and removal of dust monitors, connecting cables or tubing and airflow measurement, provision for access and inclusion of a pitot-tube arrangement are required in each section. Fig. B4 gives the arrangement of facilities for a sample volume.

Centred at 0.35 m on the side of the 1 m sections and at 0.5 m on the 1.5 m section are the pitot-tube arrangements. Behind these and making up the proportion of most of the top, outward and bottom sides are the following:

i) On the top a half and half section of a transparent medium, glass or PVC, first and wood at the back, with respect to the airflow. The latter half can be easily tapped for cable and pipe connections.

ii) On the side a transparent section incorporated with a quick release door allowing access to the duct.

iii) On the bottom a wooden section again for tapping for cables.

All these sections should be flush with the internal surface of the duct.

Access doors are also required in the 0.25 x 0.25 m cross-sections off the fan and to the sample volume off the bend. These, however, do not need to be transparent.

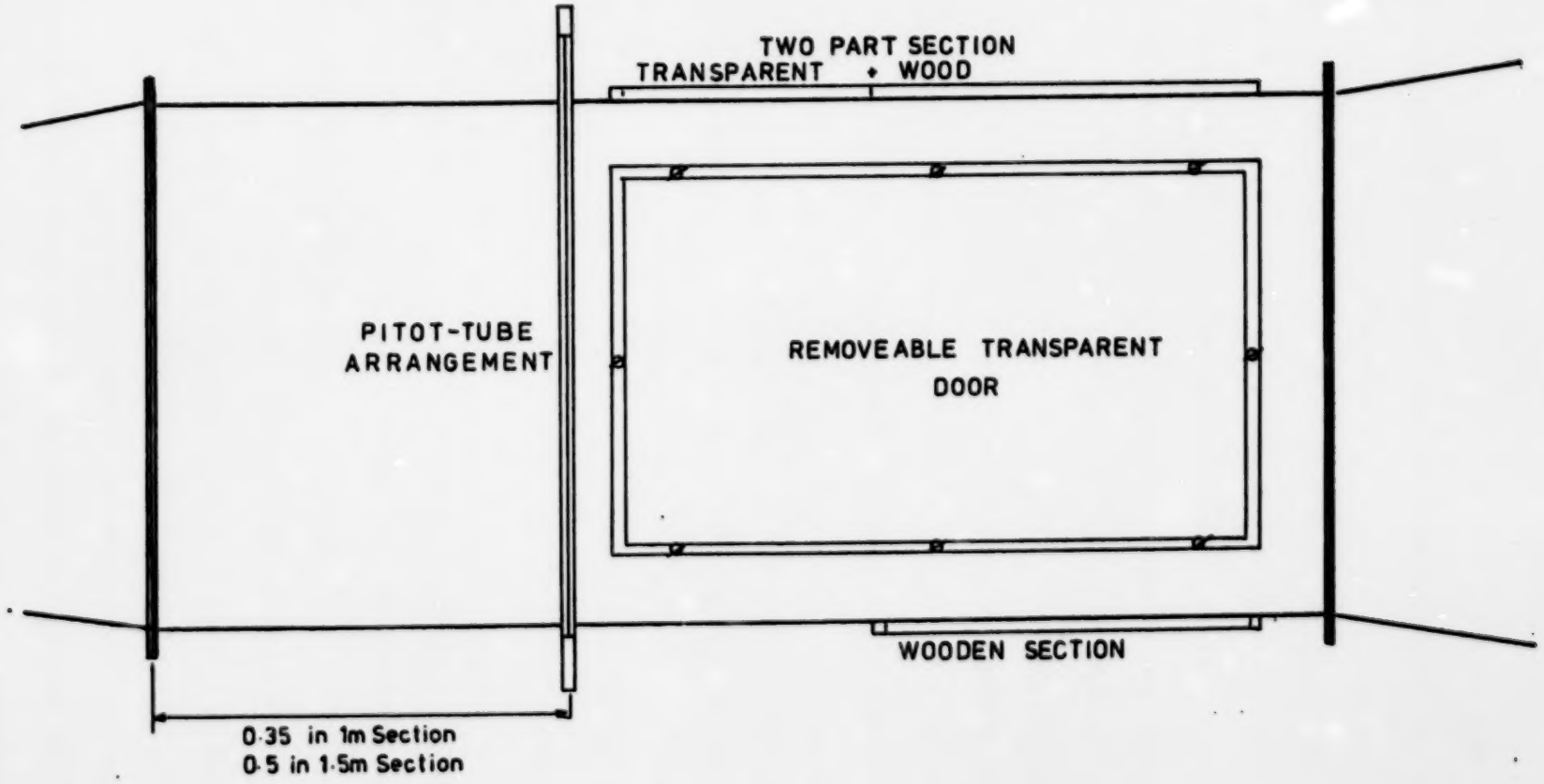

Fig. B4 - Sample volume arrangement.

PITOT-TUBE ARRANGEMENT

An arrangement is required such that a single Pitot-tube can perform a traverse of the duct cross-section to determine airflow distributions. This must allow the pitot-tube to move in both the horizontal and vertical planes.

A horizontal traverse is easily facilitated by allowing the pitot-tube to be inserted to various depths into the duct using its own length. To incorporate vertical movement the pitot-tube should be mounted in a slide attached to the side of the duct. Suggested design of this arrangement is shown in Fig. B5 and B6.

Figure B5 gives three views of the slide, the plan shows that the slide is virtually totally enclosed by its guides, apart from vertical slots running the length of the guides on the outside and the duct wall on the inside.

The side view shows that on the outside of the slide two blocks protrude through the vertical slot of the guides; these are used for clamping the pitot-tube in the horizontal plane. A recess is also shown in the side view of the slide, this is to house the head of the pitot-tube which is at 90° to the rest of the tube.

Clamping screws are also necessary in the guides to hold the slide in position.

Special care should be taken on the contact surfaces between the slide and the guides and between the slide and the pitot-tube to minimize any leaks. The maximum pressure difference experienced through a pitot-tube installation is 500 Pa. If necessary a seal may be incorporated.

Figure B6 shows the overall view of the attachment on the duct. The length of the slide will be slightly greater than twice the vertical height of the duct plus the length of the pitot-tube head recess.

To aid sealing the guides should also extend top and bottom beyond the duct dimensions. At the top the guides will extend further as it needs to

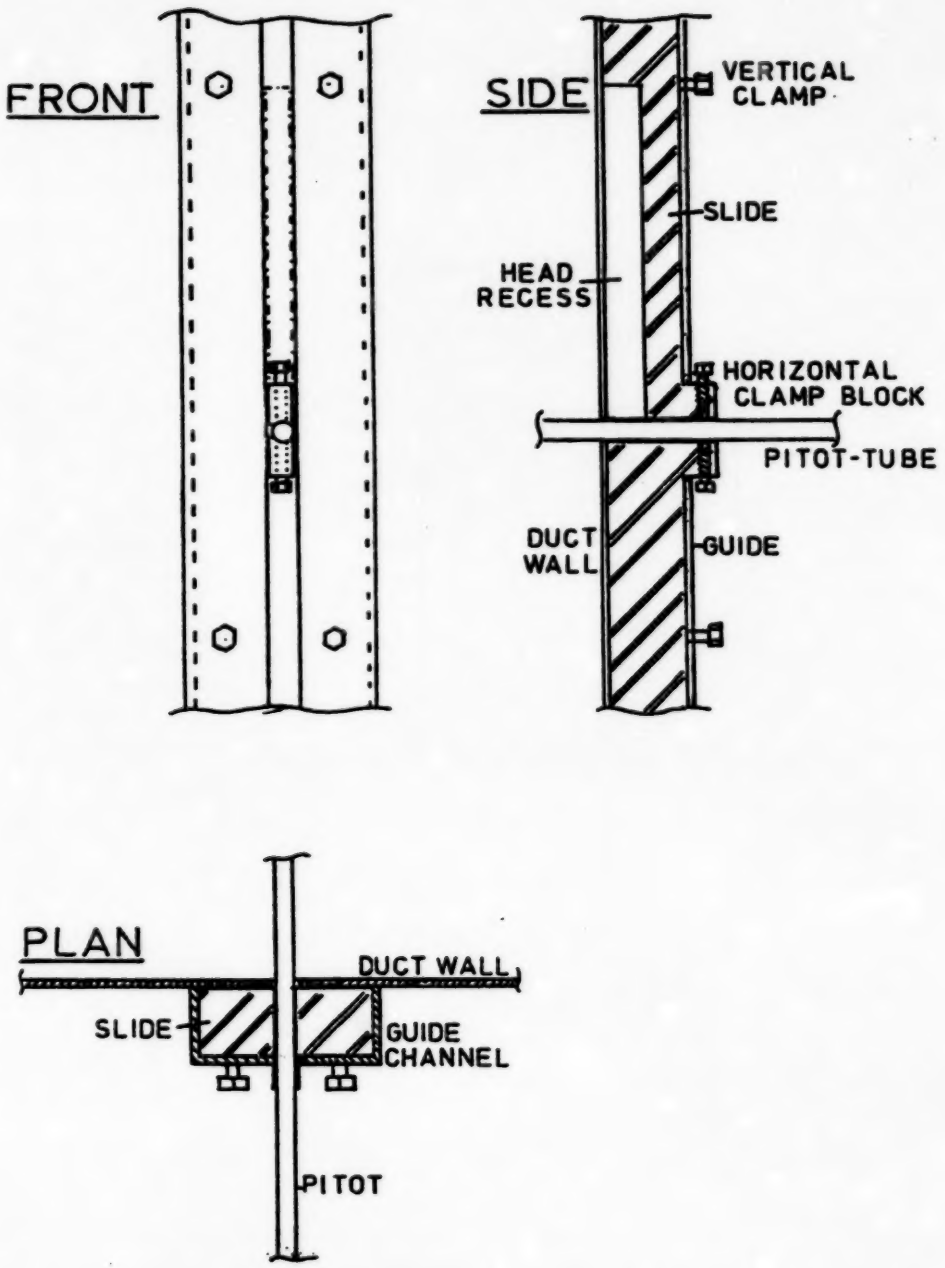

Fig. B5 - Pitot-tube arrangement.

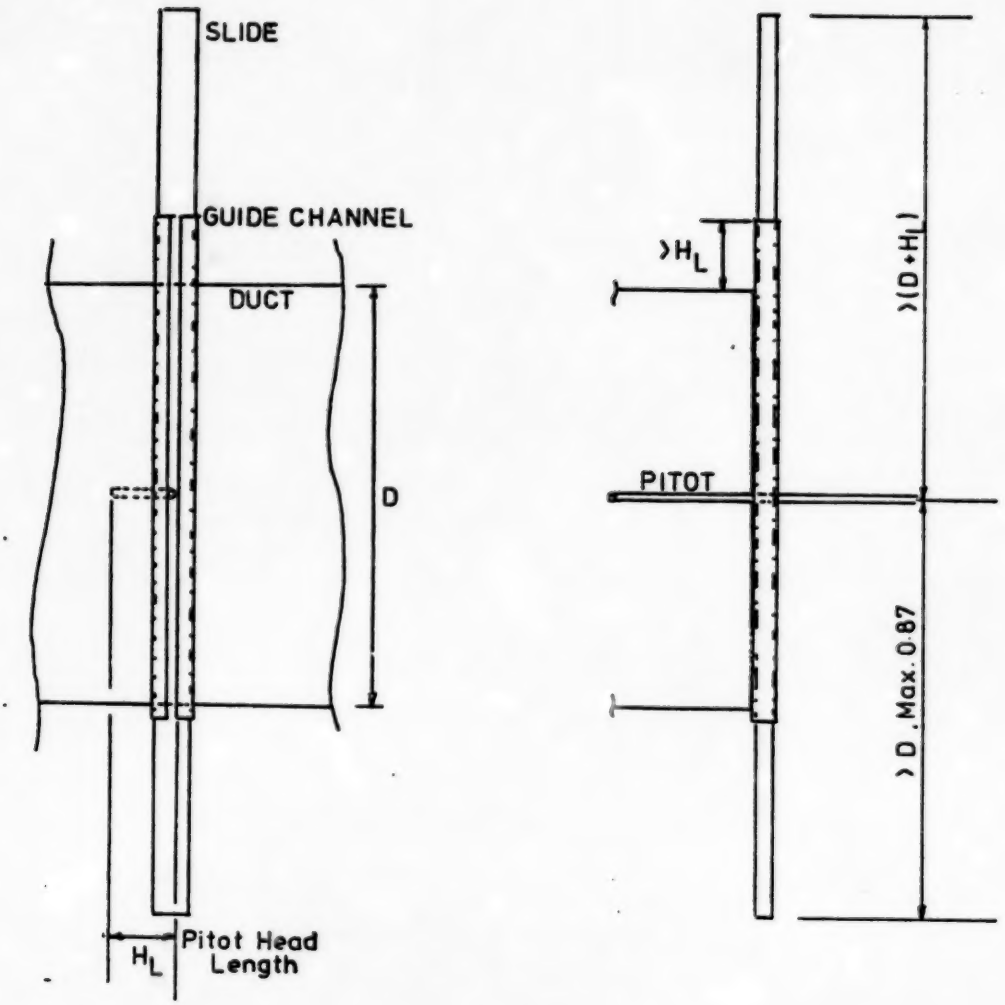

Fig. B6 - Pitot-tube slide and guide.

cover the recess when the pitot-tube is at the top of the duct.

Final dimensions of the slide, guides, recess and pitot-tube holes will depend on the dimensions of pitot-tubes used; these will be available before manufacture. Note that for the large sample volume, 0.85 x 0.85 m, the slide may only extend 0.87 m below the duct when the pitot-tube is at the bottom of its run.

When the pitot-tubes are not in use, blank slides may be inserted and the pitot-tube slide removed. The blank slide only needs to be the length of the guide channel.